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The temporal periodic variations of the total ozone content at Udaipur, a near tropical station

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Abstract : This paper attempts to discuss periodicities related to variations in the total ozone content (TOC) at a near tropical station, Udaipur (24 6°N, 73.7°E) These periodicities are related with periodicities of solar radio emission at 10 7 cm and sun spot number The Fast Fourier Transform (FFT) technique was used to obtain the power spectra, from which the periodicities were deciphered The harmonics obtained can be separated into quasi-biennial oscillation (QBO) with period of about 2 5 years, annual and semi-annual modulation with period of about 350–400 days and about 180 days, respectively, and with a period of about 27–30 days corresponding to the solar rotation period

Keywords : Total ozone content, solar radio emission, sun spot number

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1. Introduction

Ozone is one of the most important atmospheric trace gases that absorbs both, incoming ultra violet radiations from the sun and outgoing infra red rays from the earth's surface. Ozone forms a layer in the stratosphere which is thinnest in the tropics and denser towards the pole [1–3]. The amount of ozone, which is measured in Dobson unit, is about 260 DU near tropics and higher elsewhere. About 90% of total atmospheric ozone is found in the stratosphere near between 20 km to 60 km, the rest 10% ozone is found in the troposphere, near the surface of earth [4–7].

The most important role played by ozone is in the absorption of UV-B radiations (280 – 320 nm) which is the most dangerous form of UV radiations that can reach the ground level. Atmospheric ozone shields life at the earth's surface from most of the harmful components of solar radiations. Thus, its impact on biological life on earth is tremendous. If the ozone depletes, the ultraviolet radiations at Earth's surface will

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increase [8,9], endangering all forms of biological life on earth For this reason alone measurement of atmospheric ozone is necessary

After the discovery of ozone hole [10], assessment of long term and short term trends of ozone in different regions of globe has become a frontline topic of research [11–13] Several workers have also pointed out the role of nitrous oxide, chlorine and chlorofluorocarbons, produced mainly by anthropogenic activities, in the depletion of the ozone layer [14–16]

Since the incoming solar ultra violet radiation has a direct bearing on the production of ozone, variation of ozone with solar flux has been attracting researchers attention for years [17,18] The solar flux is influenced by magnetically active regions (sun spots) on the sun The solar flux increases as solar activity increases This shows that the production of ozone should be more sensitive to variations in solar flux The influence of solar activity on changes in total ozone content (TOC) has been considered by Paetzold [19,20] His analysis of vertical sounding data, for the period 1958–1968, obtained using optical ozone probes has shown that the TOC changes are related to the phase of solar activity Ruderman and Chamberlain [21] have suggested that during solar minimum condition, there is an increase in the low energy cosmic rays in the earth's atmosphere, which will increase NO_x, resulting in a decrease of ozone Variations in TOC on different time scales, ranging from 11 year solar cycle down to annual, semi-annual and 27 day solar rotation period have been reported by different workers [22–27] In some of these studies variations in ozone related to quasi biennial oscillation and planetary wave periodicities have also been reported [28] But most of these studies pertain either to the mid latitudes or the equator

The present work concerns with finding the short term and longer term periodicities in the TOC for a tropical station, Udaipur (Geog Lat 24 6° N, Geog Long 73 7° E) The data set used in this study comprises observation of the TOC, measured by the total ozone mapping spectrometer (TOMS) onboard the Nimbus-7 satellite during the period 1979–1990, encompassing the solar cycle number 20 The data are daily averages on a spatial grid with a 1° × 1 25° latitude-longitude cell, over the geographic location of Udaipur The TOC (in Dobson Units), provided by the TOMS, has been derived from the absorption of diffused solar ultra-violet emission at different wavelengths (312 nm and 331 nm) Although the satellite data suffers from the long term drift of the instrument, comparison of the TOMS data with the ground based sun photometer at Udaipur [29] and elsewhere [30] has established that the trends of TOC variations obtained by the two systems are the same.

The effect of the solar activity on changes in the TOC has been customarily investigated using the solar flux at 10 7 cm. For this purpose, we have used solar radio emission data at 10.7 cm, received by solar radio monitoring from the Dominion Astrophysics Observatory (Canada) The accessible database includes two components, the measurement of sun radio flux and its average value Each radio flux can be presented in three aspects 'observable', 'corrected', and 'URSI series D' In our case, we have used the observable radio fluxes, which are direct response by the antenna system on the received radiation The flux of radio emission at 10 7 cm is given in terms of solar flux unit, (SFU) (1 SFU = 10^{-22} WM^{-2} Hz^{-1}) It may well be argued that the solar flux at 10 7 cm may not be a true representative of the level of solar activity Since the sunspot numbers are a true representative of the solar activity, we have used the data on the daily values of the sunspots during the period 1979 to 1990 obtained from SIDC, Royal Observatory, Belgium All the three time series, namely, the TOC, solar flux and the sunspot numbers were subjected to the Fast Fourier Transform (FFT) analysis separately, to determine various periodicities associated with each

2 Methodology

The fast Fourier Transform (FFT) technique has been used to extract the periodicities associated with the quasi periodical fluctuations in the time series It is known that any signal of a natural origin represents a set of spectral harmonics, which can be represented as the sum of regular harmonics only under specific approximations Thus, the physical interpretation of such a signal is problematic Using standard Fourier decomposition, this problem can be solved

FFT, which is generally applicable on continuous time series, can be applied to discrete one, provided that the sampling period is small [31] In our case, the sampling period is one day and total no of days is 4096 Hence the highest frequency that could be detected corresponds to a time period of two days

When a non periodic time series is subjected to the FFT analysis, the resulting spectrum suffers from the leakage As a result of this leakage, the signal energy smears out over a wider range of frequencies in the FFT whereas it should have been in a narrow range of frequency [32] The problem of leakage can be reduced, but not eliminated through the use of a suitable windowing function A number of window functions are being employed, depending on the type of data, admissible spectral leakage, required frequency resolution and amplitude accuracy Hanning window function is one which is commonly used in geophysical applications and qualifies to be good *vis-a-vis* the three points mentioned above [32] Therefore, the data was filtered through a Hanning window prior to the FFT computation

The FFT analysis provides amplitude (real and imaginary parts) at each frequency, from which power can be calculated Thus the absolute random error associated with each power estimate would be 100%, as the error is equal to $\sqrt{(2/N)}$, where N is the number of degrees of freedom (2 in the present case) In power spectral analysis, to reduce this error, smoothing over frequency or over segments is normally employed But that under estimates the amplitudes of the peaks, resulting in suppression of periodicities Hence, we have not performed the smoothing Only those peaks in the spectrum would be considered which would stand out clearly

3. Results and discussion

Figure 1 gives a plot of total ozone content at Udaipur for the period 01/01/1979 to 12/05/1990. The chosen period corresponds to a total of 4096 (= 2^{12}) days, or the data points. This number is so chosen because the analysis by the FFT requires the number of data points to be an exact power of 2.

In this figure, the annual variation is clearly seen. There are broad maxima that occur around April-June and minima around November-December. The pattern is in conformity with the earlier studies for the tropical region [1,33]. The annual average of the TOC is about 260 DU. Along with this, many larger and small periodicities might be hidden and could be extracted through the FFT analysis.

Figure 2 gives the power spectrum of the TOC data given in Figure 1. In power spectrum analysis, it is customary to plot the spectral power density *versus* the frequency. But in the present case the abscissa is Time (number of days), which is the inverse of the frequency. This has been done to relate the quasi periodicities in terms of the number of days, such as annual and semi-annual.

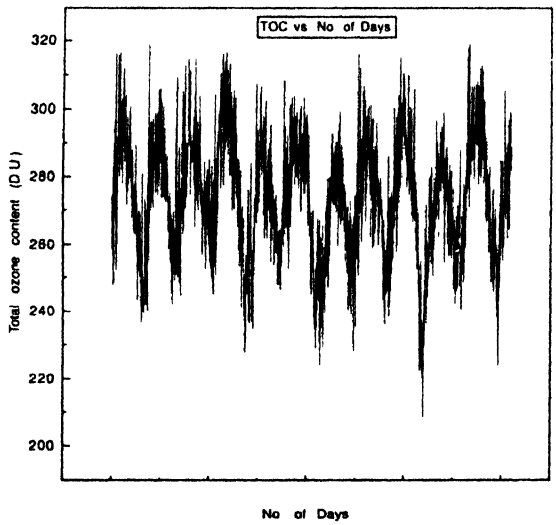

Figure 1. Total columnar ozone measured by TOMS over Udaipur from January 1979 to December 1992. Annual variation in TOC is observable clearly. The maxima and minima occur during April-June and November-December, respectively.

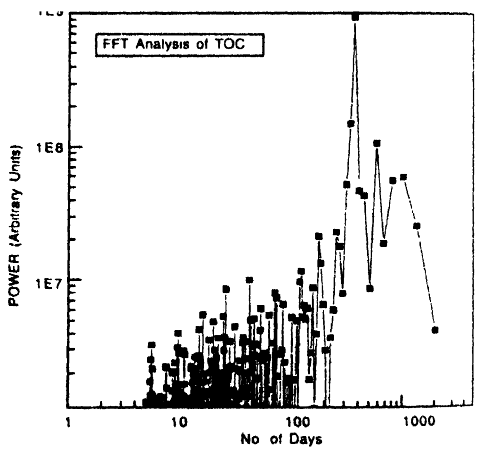

Figure 2. Result of power spectrum analysis of the TOC for the period 1/1/1979 to 12/5/1990 The annual, semi-annual periodicities and the ones associated with the QBO and the solar rotation period (27 days) are observed clearly.

The spectrum shows a number of prominent peaks which could be identified as steady quasi periodical processes observed on select periodicities. The strongly marked annual component and the components with a period of about 2.7 years and 1.7 years are easily distinguished. Similar periodicities have also been reported in previous [23,33] and recent work [34]. The component at 2.7 year is the quasi biennial component. Its power changes with time, reaching maximum at end of each solar cycle [34]. Thus, as opposed to the annual component with a constant period, the quasi biennial component represents the sum of two close range harmonics with periods of 1.7 and 2.7 years. These components are probably connected with the well known quasi-biennial fluctuations of the stratospheric winds above the equator (QBO variations).

Besides, a number of components with periods ranging from 180 days (semi-annual) to 27 days (connected with the solar rotation period) are also observed.

To study the solar activity influence on the TOC, we have used coincident time series of the TOC and the radio emission data, represented by the solar flux at 10.7 cm. A plot of the solar flux for the period 1/1/1979 to 31/12/1992 is given in Figure 3. Beside the 11-year solar cycle variation of the flux, a number of periodicities could be associated. These could be brought out through the FFT analysis.

The power spectrum analysis of the solar flux at 10.7 cm is shown in Figure 4 The low frequency component seen around 4.2 years may represent a sub-harmonic of the 11 year solar cycle. The work by Sych *et al* [36] also reveals a similar sub-harmonic at about 5 years. The other two components observed at 180 and 400 days could be associated with the semi-annual and annual periodicities respectively. The 27 day periodicity is also visible which is probably connected to the rotation period of the sun.

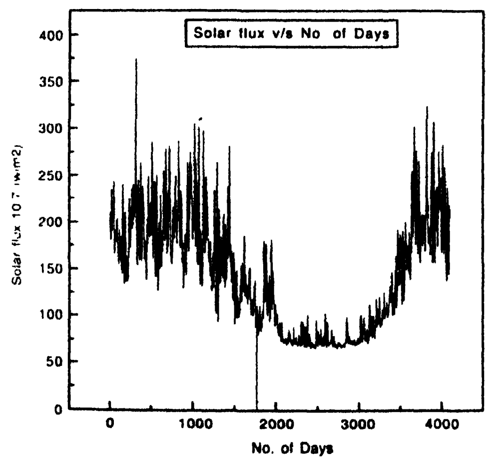

Figure 3. Solar flux data measured by Dominion Astrophysics Laboratory, Canada from January, 1979 to December, 1992. The 11-year solar cycle variation and the annual periodicities are obvious.

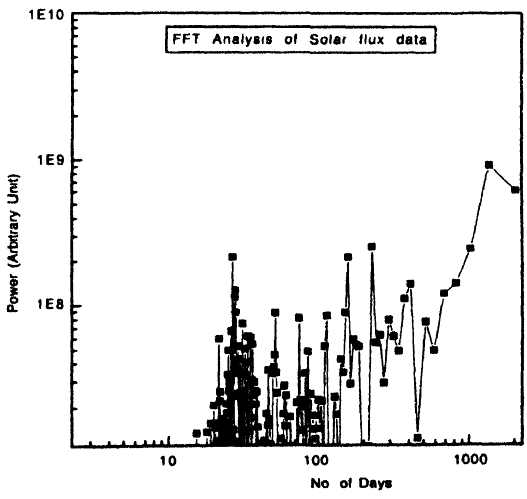

Figure 4. Result of power spectrum analysis of the solar flux data for the period 1/1/1979 to 12/5/1990. The annual, semi-annual periodicities and the ones at 4.2 year, 250 days and the solar rotation period (27 days) are observed clearly.

As discussed earlier, the sun spot number could be a better representative of the solar activity, periodicities in the TOC have been compared with the ones in the sun spot numbers. Figure 5 shows the plot of the sun spot numbers for the period January 1979 to December 1992. The plot grossly resembles that of the solar flux data. The 11-year solar cycle variation is seen conspicuously.

In this figure, the 11 year cycle variation is seen clearly. There are two broad maxima and a minimum. Along with this, many large and small periodicities of annual semi annual and solar rotation might be hidden and could be extracted through the FFT analysis.

Figure 6 shows the power spectrum of sun spot number of data plotted in Figure 5.

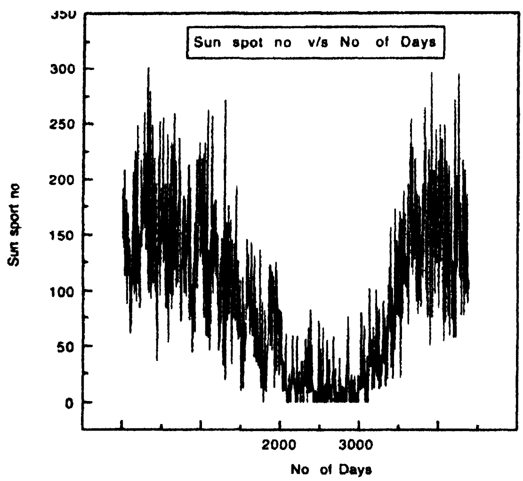

Figure 5. A plot of the sun spot numbers measured by SIDC, Royal Observatory, Belgium from January 1979 to December 1992.

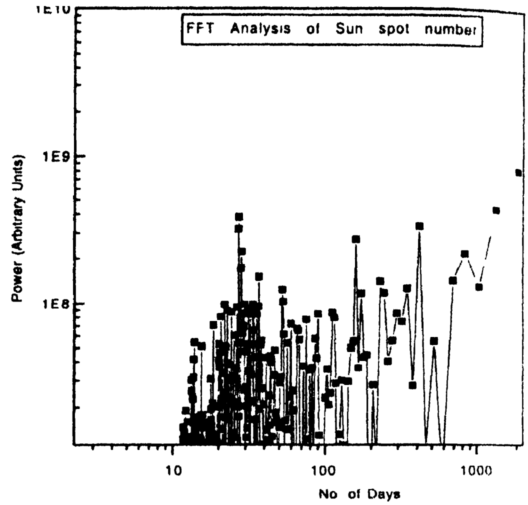

Figure 6. Result of power spectrum analysis of the sun spot number for the period 1/1/1979 to 12/5 1990 The annual, semi-annual periodicities and the ones at 2 2 year and the solar rotation period (27 days) are observed clearly.

The spectrum shows two prominent peaks at 400 and 800 day. Peak at 400 day could be identified as annual component. Beside these, a number of components with periods ranging from 180 days (semi-annual) to 27 days (connected with the solar rotation period) are also observed.

4. Conclusions

In this study, we have applied the fast Fourier transform to obtain the periodicities in the TOC spanning about a solar cycle. The dominant periodicities in the TOC are the QBO, annual, semi-annual and those related to the solar rotation period. In order to look for the causes of these periodicities, the solar radio emission data at 10.7 cm and the sun spot number data for the same solar cycle were also subjected to the FFT analysis. For these data also, the obtained spectrum could be divided into harmonics with solar periodicities, namely, the quasi-biennial oscillation (2.5 years), annual and semi-annual periodicities (365 and 180 days) and modulation with periods of 27 days related to the solar rotation. It appears that the periodicities in the TOC follow that in the solar flux as well as the sunspot numbers.

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